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I hereby submit the papers I presented at the 26th General Assembly of the International Union of Geodesy and Geophysics, held in Prague, Czech Republic between 22nd of June and 2nd of July, 2015. The title of the first paper is "Climate, Runoff and Land Use Trends in the Owo River Catchment in Nigeria" and the title of the second paper is "Changes in Flood Risk in the Lower Niger-Benue Catchments. Attached are copies of the papers for the University Library.

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# Climate, runoff and landuse trends in the Owo River Catchment in Nigeria

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**Abstract.** The Owo River is an important surface water source in Lagos particularly to the western section. It is the source of direct water intake for water supply by Lagos State Water Corporation to Amuwo-Odofin, Ojo and parts of Badagry Local Government Areas. This paper examines the complex interactions and feedbacks between many variables and processes within that catchment and analyses the future ability of this semi-urban watershed in sustaining water supply in the face of cumulative environmental change. Stationarity analysis on rainfall, change detection analysis and morphometry analysis were combined to analyse the non-stationarity of Owo River catchment. On rainfall trend analysis, since the correlation coefficient (0.38) with test statistic of 2.17 did not satisfy the test condition we concluded that there is trend and that rainfall in the watershed is not stationary. The dominant land use impacting on the bio-geochemical fluxes is built up area (including structures and paved surfaces) which grew from about 142.92 $km^2$ (12.20 %) in 1984 to 367.22 $km^2$ (31.36 %) in 2013 recording gain of 224.3 $km^2$ at average growth rate of 7.73 $km^2$ per annum. Total length of streams within the catchment reduced from 622.24 km in 1964 to 556 km in 2010, while stream density reduced from 0.53 in 1964 to 0.47 in 2010 an indication of shrinking hydrological network. The observed trends in both natural and anthropogenic processes indicated non-stationarity of the hydrological fluxes within the Catchment and if this continues, the urban ecosystem services of water supply will be compromised.

## 1 Introduction

The Owo River is an important surface water source in Lagos particularly to the western section. It is the source of direct water intake for water supply by Lagos State Water Corporation to Amuwo-Odofin, Ojo and parts of Badagry Local Government Areas. The watershed of the Owo River has undergone a number of changes in recent decades. These observed changes can be attributed to both natural and anthropogenic factors including climate change, landuse–landcover changes and urbanization amongst others. The changes have been observed to have impacts on some of the basin morphometric characteristics with concomitant consequences for water resources availability within the watershed. Basin physical properties have direct relationships with water resources availability and any change in stream properties can translate to reduction or increase in water yield and availability (Ojo et al., 2003). Also, high variability of rainfall characteristics is becoming more pronounced, a condition that is impacting seriously on raw water abstraction from Owo River for municipal water supply at Ishashi intake. Urbanization is also impacting on the hydrological response of the catchment, thereby contributing to the non-stationarity or otherwise of the catchment. This paper examines the complex interactions and feedbacks that have brought about changes in hydrological and morphological characteristics of the watershed and analyses the future ability of this semi-urban watershed in sustaining water supply in the face of cumulative environmental change.

## 2 Study area

Owo River Catchment is one of the watershed south of Ogun River Basin in South Western Nigeria. Its perculiarity can be attributed to its locaton, which is within the Lagos Mainland and it is the main source of water to Ishasi Waterworks. Geographically, it extends between latitudes 6°27′23″ and

6°54′22″, and longitudes 3°16′60″ and 3°4′6″. The major river, "Owo" drains about 12 Local Government Areas, 2 in Ogun State and 10 in Lagos State and has a total length of 71.15 km. It runs through as a tributary of River Ore in Ogun State and ends up in the Ologe Lagoon. River Owo has a safe yield of 28 million gallons per day MGD (127.1 million L per day [MLD]), which translates to a monthly average of about 840 MGD (3813 MLD). The catchment has about 156 settlements and covers about 1170.68 km$^2$ (Fig. 1). Agricultural activities remain the dominant human activities, although over the years the catchment has witnessed changes due to urbanization. The river supplies raw water to the Isashi Waterworks located at the Oto-Ijanikin Local Council Development Area of Lagos State. The Waterworks was constructed in 1974 jointly by the Federal Government of Nigeria and the Lagos State Government to supply water to the western part of the Lagos metropolis, thus it was designed to serve Amuwo-Odofin, Festac, Ojo, Satellite Town, Ijanikin and other settlements along the axis (Lagos State Water Corporation, LSWC, 2011).

The climate is humid tropical with a mean annual rainfall of about 2721 mm. Mean annual number of rain days is about 170, mean monthly rainfall is about 229 mm and mean annual temperature is about 27.8 °C. The geology of Owo River catchment which is generally described as Ilaro Formation comprises of marine and continental deposits and rocks of sedimentary origin. The vegetation of the catchment is composed of heavy forest, derived forest and intensive riparian forest along the drainage paths. (National Atlas of the Federal Republic of Nigeria, 1978). Figure 1 shows the location of Owo River catchment in Lagos and Ogun States.

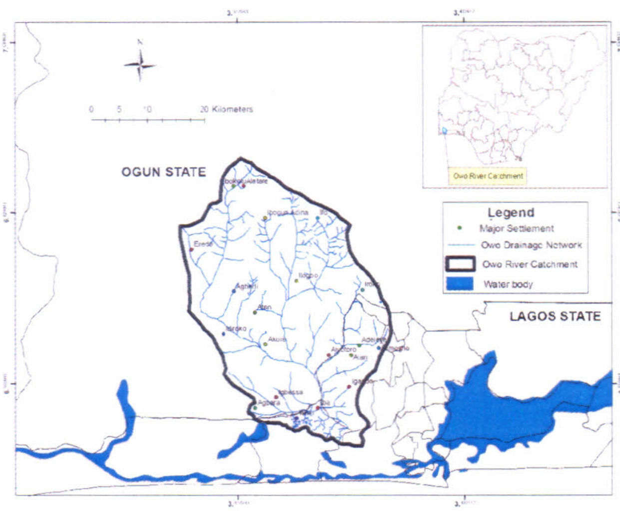


**Figure 1.** Owo River Catchment.

## 3 Methodology

Monthly rainfall data (Abeokuta and Lagos stations) for the period 1981–2011 was obtained from the Nigerian Meteorological Agency (NIMET), to establish the non-stationarity of rainfall through various statistical tests including; Spearman's Rank Order Correlation Test to verify the presence or absence of trend in the time series, the Mann–Whitney $U$ test to detect if there is a shift in the mean of the rainfall time series (stability of mean) and cumulative deviations or departure test (CUSUM) to check for homogeneity and changes in the underlying mean of the time series (Dahmen and Hall, 1990; Machiwal and Jha, 2012). The freshwater abstraction and supply for years 2004–2011 at the waterworks were examined for temporal variability using $F$ test or Fisher distribution and the coefficient of variation (CV). To determine the land use change, pragmatic hierarchical land use classification scheme following Nigeria topographic mapping was adopted. The dataset used for land use mapping is shown in Table 1. The change analysis was conducted on images of 1984, 2000 and 2013. Certain numbers of training datasets were randomly sampled from the spectral signature of each of the classes to define their respective landuse/landcover type.

The change detection analysis was performed using ENVI analytical tool to extract the image difference between the two periods of time. Other analysis carried out includes area calculation of the landuse/landcover change for the three static years (1984, 2000 and 2013). Comparative analysis of morphometric dynamics of the catchment was carried using drainage dataset derived from Nigeria Topographical Map series of 1964 and ASTER-DEM of 30 m spatial resolution of 2010. The topographic sheets that covered the basin were mosaicked, geometrically rectified and georeferenced to World Space Coordinate System. The mosaicked sheets were spatially aligned or adjusted to the Landsat image to maintain spatial accuracy. Thus, the drainage network pattern of 1964 was therefore extracted from the mosaicked topographical sheets. Likewise, using the ArcHydro extension tool of Arc GIS 10.2, the drainage pattern of 2010 from the ASTER-DEM was also extracted for comparative analysis of the morphometric variables. Spatio-temporal morphometric variables were examined between these two sources of drainage network patterns. These include bifurcation ratio, drainage density, stream frequency, drainage intensity and stream length.

## 4 Results and discussion

### 4.1 Rainfall non-stationarity

The analysis of annual rainfall data shows the existence of trend in the rainfall time series which is an indication of non-stationarity in a hydro-climatic time series. Although this existence of trend in the hydrologic time series which is an indication of low frequency oscillatory movement cannot be totally explained by local players including land use change

**Table 1.** Data sources and characteristics.

| Data | Year | Instrument | Resolution | Source |
|---|---|---|---|---|
| LANDSAT TM | 1984 | Thematic Mapper7,4,2 bands | 30 m | |
| LANDSAT ETM | 2000 | Enhanced TM-7,4,2 bands | 30 m | USGS, glovis.org |
| LANDSAT 8 | 2013 | OLI-5,3,2 bands | 30 m | |
| Topographic Map | 1964 | 279 NW, SW, NE, NW | 1 : 50 000 | Federal Survey Lagos |
| ASTER-DEM | 2010 | NO6E002, NO6E003 | 30 m | USGS, earthexplorer.org |

at catchment level, they however, do contribute significantly to the micro climate and the dynamics that exist in rainfalls (Kottegoda, 1980). The positive correlation ($R_{sp} = 0.38$) is an indication of upward trend in annual rainfall. Also, the null hypothesis of equal mean is rejected because the test statistic ($U_c$) was calculated as 86 as against the critical value of ($U$) equal 70 at 5 % significance level. It was therefore, concluded that there has been a shift in the mean of the rainfall time series which implies the instability of mean and non stationarity of the time series.

The result of the Mann–Whitney $U$ test shows that the mean of the subseries of rainfall are unequal, indicating instability in the mean. The mean of the yearly rainfall time series for the first subseries ($\overline{X}K_1 = 1257$ mm) differ from the mean of the second subseries ($\overline{X}K_2 = 11\,421.8$ mm). The cumulative departures from the mean, $\Sigma(XK_1 - \overline{X}K_1)$ and $\Sigma(XK_2 - \overline{X}K_2)$ shown in Table 2 and illustrated in Figs. 2 and 3 showed non-stationarity in the annual rainfall of the watershed. The positive slopes on the charts of the subseries indicate a period of above average values corresponding to wet years, while negative slopes indicates a below average period or dry years.

## 4.2 Impact of non-stationarity on water supply

Owo River is an unregulated river. Raw water is being abstracted through direct intake on the river, and therefore the free flow, variation and variability (fluctuations) of water level and other natural processes of the river in its natural course is not obstructed in any way. Between 2004 and 2011, the volume of raw water abstracted varied between a minimum of 433.4 million L in 2010 to maximum of 2207.7 million L in 2008 while the volume supplied ranged between a minimum of 392.5 million L in 2010 and a maximum of 2051.5 million L in 2008. Average volume of water abstracted between 2004 and 2011 was 1437.3 million L while an average of 1344.1 million L was supplied within the same period. Results of the $F$ test shows that no significant difference exists in the annual water abstraction ($F_t < F_{0.05} = 1.65 < 9.3$) and annual water supply ($F_t < F_{0.05} = 1.67 < 9.3$) at the stated level of significance. The computed value of $F_t$ is less than its critical value hence we accept the null hypothesis and conclude that no significant difference exists in the annual water abstraction as well as water sup-

**Table 2.** Cumulative Departures from the mean of the two time series.

| Rainfall time series I (Subset I) | | | Rainfall time series II (Subset II) | | |
|---|---|---|---|---|---|
| Year | $Xk_1$ | $\Sigma(XK_1 - \overline{X}K_1)$ | Year | $Xk_2$ | $\Sigma(\overline{X}K_2 - \overline{X}K_2)$ |
| – | – | 0.00 | – | – | 0.00 |
| 1981 | 1463.35 | 205.65 | 1996 | 1523.5 | 101.7 |
| 1982 | 902.55 | −149.5 | 1997 | 1687.4 | 367.3 |
| 1983 | 895 | −512.2 | 1998 | 1079.15 | 24.65 |
| 1984 | 1245.8 | −524.1 | 1999 | 1476.4 | 79.25 |
| 1985 | 1160.35 | −621.45 | 2000 | 1230.5 | −112.05 |
| 1986 | 918.8 | −960.35 | 2001 | 1121.15 | −412.7 |
| 1987 | 1476.45 | −741.6 | 2002 | 1496.05 | −338.45 |
| 1988 | 1774.6 | −224.7 | 2003 | 1459.65 | −300.6 |
| 1989 | 1384.75 | −97.65 | 2004 | 1434.2 | −288.2 |
| 1990 | 1208.55 | −146.8 | 2005 | 1204.55 | −505.45 |
| 1991 | 1439.65 | 35.15 | 2006 | 1408.65 | −518.6 |
| 1992 | 1130.2 | −92.35 | 2007 | 1632.4 | −308 |
| 1993 | 1444.6 | 94.55 | 2008 | 1593.85 | −135.95 |
| 1994 | 1016.65 | −146.5 | 2009 | 1428.6 | −129.15 |
| 1995 | 1403.65 | −0.55 | 2010 | 1550.7 | −0.25 |
| | $\overline{X}k_1 = 1257.7$ | | $\overline{X}k_1$ | 1421.8 | |

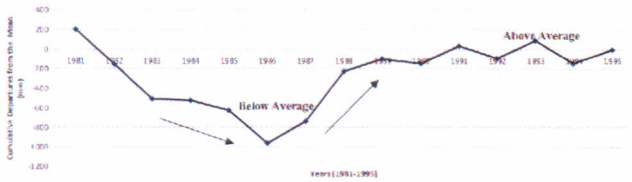


**Figure 2.** Cumulative departures from the mean for Subset 1 (1981–1995).


**Figure 3.** Cumulative departures from the mean for Subset 2 (1996–2010).

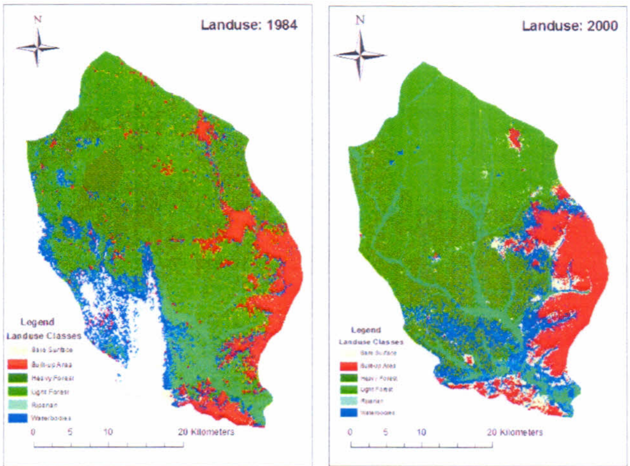


**Figure 4.** Landuse dynamics of Owo River Basin between 1984 and 2000.

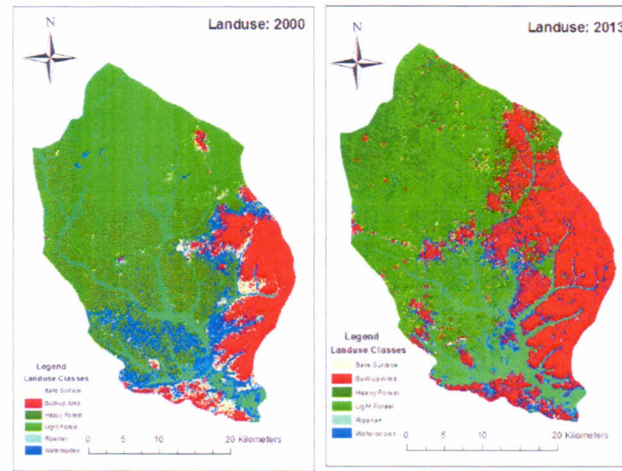


**Figure 5.** Landuse dynamics of Owo River Basin between 2000 and 2013.

ply at 5 % level of significance. It can be concluded that the non-stationarity of Owo River Catchment has not critically affected water supply from the catchment. However, 42.49 % (CV) for abstraction and 42.60 % (CV) for water supply indicate the existence of high level of variation in the annual water abstraction and annual water supply at the waterworks.

## 4.3 Landuse change analysis

Table 3 shows the land use changes in $km^2$ and percentage of land uses. In each of the periods, built-up area remains the dominant landuse with a progressive landuse change that increased from 12.20 % in 1984 to 20.69 and 31.36 % in 2000 and 2013 respectively. The patterns of the changes over these periods of time are shown in Figs. 4 and 5. The changes reveal increasing human activities in the area.

Tables 3 and 4 describe the change matrix; the diagonal figures highlighted in bold represent the percentage of landuse/landcover classes that have remained in the same locations (area of stability) (Odunuga et al., 2011) while other matrices indicate the change to the principal landuse (Table 5).

**Table 3.** Landuse dynamics of Owo River Basin in 1984, 2000 and 2013.

| | Landuse in 1984 | | Landuse in 2000 | | Landuse in 2013 | |
|---|---|---|---|---|---|---|
| | Area ($km^2$) | % | Area ($km^2$) | % | Area ($km^2$) | % |
| Built-up area | 142.92 | 12.20 | 242.33 | 20.69 | 367.22 | 31.36 |
| Heavy forest | 331.79 | 28.34 | 298.38 | 25.48 | 259.61 | 22.17 |
| Waterbodies | 162.38 | 13.87 | 143.47 | 12.25 | 98.63 | 8.42 |
| Light forest | 292.43 | 24.97 | 285.27 | 24.36 | 261.33 | 22.32 |
| Riparian | 155.12 | 13.25 | 133.79 | 11.42 | 122.47 | 10.46 |
| Bare surface | 12.03 | 1.02 | 67.44 | 5.76 | 61.42 | 5.24 |
| Cloud cover | 74.01 | 6.32 | – | – | – | – |
| Total | 1170.68 | 100 | 1170.68 | 100 | 1170.68 | 100 |

## 4.4 Morphometry dynamics

Tables 6 and 7 reveal the morphodynamics of the Owo River catchment between 1964 and 2010. These variations are shown in the spatial properties or dimensions of the river basin. The result shows that the Owo River catchment is a 4th-order river catchment which has the capacity to drain a relatively large area, with a considerable kinetic energy to transport, erode and deposit sediments.

Comparison of the morphometric properties of the catchmen between the two periods shows that there are variations in the numbers of streams, stream length and bifurcation ratio. Within the study period first and second order streams have greatly reduced. Thus, some of the first-order streams are lost to anthropogenic activities. This situation has serious implications on the water yield within the catchment. Table 7 shows changes in other morphometric indices within the catchment while Fig. 6 shows the morpho-dynamic characteristics of the Owo River Basin between 1964 and 2010.

## 5 Conclusion

The study has shown that the Owo river catchment is a highly dynamic catchment as can be deduced from the non-stationarity of rainfall and the anthropogenic induced land use and hydro-morphometric changes that has occurred in the last four decades. The observed changes therefore call for sustainable catchment management practices that ensure ecofriendly development that do not compromise environmental integrity of the catchment and sustainable urban water supply.

**Table 4.** Change detection matrix between 1984 and 2000 (%).

| | Built-up | Heavy forest | Waterbodies | Light forest | Riparian | Bare surface |
|---|---|---|---|---|---|---|
| Built-up area | **11.058** | 2.455 | 9.631 | 9.317 | 0.853 | 41.355 |
| Heavy forest | 0.716 | **36.662** | 40.852 | 20.623 | 28.981 | 13.945 |
| Waterbodies | 1.233 | 7.293 | **14.764** | 9.24 | 20.825 | 14.767 |
| Light forest | 1.67 | 38.859 | 19.95 | **50.636** | 11.81 | 4.922 |
| Riparian | 83.107 | 11.525 | 8.039 | 4.354 | **34.6** | 2.104 |
| Bare surface | 2.216 | 3.206 | 6.764 | 5.829 | 2.864 | **22.906** |
| Class total | 100 | 100 | 100 | 100 | 100 | 100 |
| Class changes | 88.942 | 63.338 | 85.236 | 49.364 | 65.333 | 77.094 |
| Image difference | −81.83 | 2.213 | −11.639 | 18.01 | 511.852 | 459.987 |

**Table 5.** Change detection matrix between 2000 and 2013 (%).

| | Built-up | Heavy forest | Waterbodies | Light forest | Riparian | Bare surface |
|---|---|---|---|---|---|---|
| Built-up | **93.241** | 12.628 | 32.863 | 13.178 | 0.152 | 73.555 |
| Heavy forest | 0.436 | **30.595** | 12.877 | 42.872 | 3.133 | 2.466 |
| Waterbodies | 4.715 | 10.981 | **16.706** | 3.928 | 0.675 | 16.447 |
| Light forest | 0.158 | 30.742 | 5.226 | **35.855** | 3.022 | 0.941 |
| Riparian | 0.189 | 12.31 | 29.848 | 1.339 | **7.873** | 1.728 |
| Bare surface | 1.261 | 2.744 | 2.481 | 2.828 | 85.145 | **4.863** |
| Class total | 100 | 100 | 100 | 100 | 100 | 100 |
| Class changes | 6.759 | 69.405 | 83.294 | 64.145 | 92.127 | 95.137 |
| Image difference | 115.554 | −12.13 | −31.253 | −24.34 | −81.038 | 973.443 |

**Table 6.** Morphometry dynamics of Owo River Basin.

| Stream order | River: 1964 | | | River: 2010 | | |
|---|---|---|---|---|---|---|
| | Number | Length | Bifurcation | Number | Length | Bifurcation |
| 1 | 218 | 322.71 | 2.20 | 160 | 297.97 | 1.95 |
| 2 | 99 | 158.56 | 1.34 | 82 | 149.45 | 2.83 |
| 3 | 74 | 92.33 | 2.18 | 29 | 51.36 | 1.45 |
| 4 | 34 | 48.64 | – | 20 | 57.20 | – |
| Total | 425 | 622.24 | – | 291 | 555.98 | – |

**Table 7.** Changes in other morphometric indices of Owo River Basin.

| Morphometric variables | River: 1964 | River: 2010 |
|---|---|---|
| Drainage density (mi mi$^{-2}$) | 0.53 | 0.47 |
| Stream frequency (mi mi$^{-2}$) | 0.0003 | 0.0002 |
| Drainage intensity (mi mi$^{-2}$) | 0.00056 | 0.00042 |

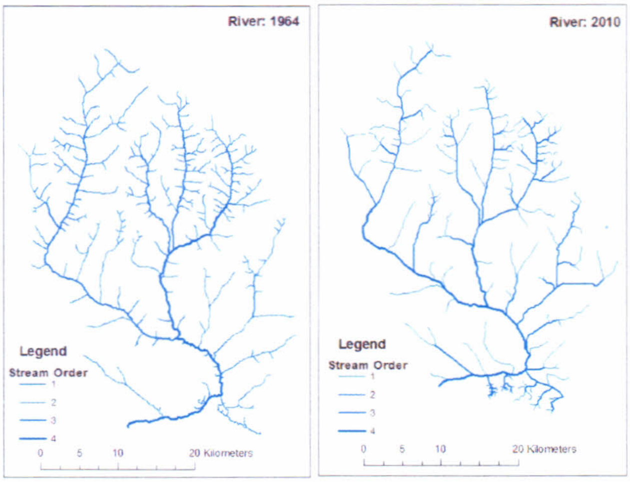


**Figure 6.** Morphodynamic characteristics of Owo River Basin between 1964 and 2010.

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# Changes in flood risk in Lower Niger–Benue catchments

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**Abstract.** Floods are devastating natural disasters with a significant impact on human life and the surrounding environment. This paper analyses historical and recent flood (2012 extreme) peak flow at strategic locations, land use activities and Floodplain Vulnerability Index analyses of the Niger–Benue River Floodplain. The 2012 peak flow at Jederbode on the Niger River was about 50 % above the long term average. At Jebba (Niger), the 2012 peak flow of 1567 $m^3\,s^{-1}$ was also far higher than the long term mean annual peak flow of 1159 $m^3\,s^{-1}$. The 2012 peak flow at Lokoja was also about 50 % above the historical average. The Benue River at Makurdi had peak flow of 16 387 $m^3\,s^{-1}$ which was also unusually higher than the historical average while Wuroboki (Benue) had peak flow of 3362 $m^3\,s^{-1}$ which was also much higher that the historical average (694 $m^3\,s^{-1}$). The mixed land use which supported diverse ecosystem services has the largest cover of 5654 $km^2$ (36.85 %) of the Niger–Benue floodplain. The flood vulnerability of the various land uses within the floodplain include; medium, high and very high levels. A four levels hierarchical implementation adaptation strategy for sustainable agricultural practices along the rivers flood plain was proposed. The implementation hierarchy includes: Community Concern, Local Authority Concern, State Concern and National Concern.

## 1 Introduction

Floods are natural disasters with a significant impact on human life and the surrounding environment. It occurrence worldwide has claimed many lives, displaced millions and cause the destruction of properties and degradation of contiguous farmlands, wetlands, forest and other natural resources of the environment. It is the most frequent disaster in the world and widely distributed, leading to significant economic and social damages than any other natural disaster (DMSG, 2001). Flood may be defined in a number of ways, according to type, origin and magnitude. Generally, it is an unusual high stage of water usually above the bank of its flow path (artificial or manmade). When it causes damage to goods and properties or impairs human activities, it becomes a hazard (Odunuga et al., 2012). However, recent events in terms of frequency, magnitude, extent and extreme of flooding events have shown that flood risk (probability that exposure to flood hazard will lead to a negative consequence) along the lower Niger–Benue floodplain is on the increase. Between July and October 2012, flooding in Nigeria caused rivers especially the Niger and Benue Rivers to overflow their banks and submerged hundreds of thousands of acres of farmland. By mid-October, floods had forced 1.3 million people from their homes and claimed 431 lives, according to Nigeria's National Emergency Management Agency. This paper analyzes historical and recent flood (2012 extreme) peak flow at strategic locations, the land use and Floodplain Vulnerability Index analyses of the Niger–Benue River Floodplain. It develops a hierarchical adaptation strategy for sustainable use of the Niger–Benue River floodplain.

## 2 Study area

The Niger River Basin covers 2.27 million $km^2$, with the active drainage area comprising less than 50 % of the total (Oyebande and Odunuga, 2010). At 4200 km in length, the Niger is the third longest river in Africa and the world's ninth largest river system. The basin is shared among 10 countries: Nigeria (27 %), Mali (26 %), Niger (24 %), Algeria (8 %), Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire and

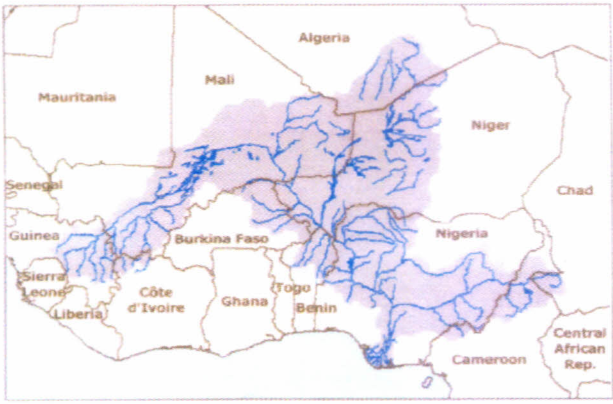



**Figure 1.** Niger and Benue in West Africa.

Guinea (each < 5 %). The study area falls within the Nigeria section and include the Benue (the Niger major tributary) that join it at Lokoja. Figure 1 shows Niger basin and its tributary Benue River in West African respectively. Annual rainfall ranges from about 1100 mm in the upstream basement complex area, to about 1400 mm south of Lokoja.

## 3 Methodology

Historical flow data (1960 to 2012) from Lokoja (Niger–Benue Confluence), Jederbode (Niger), Jebba (Niger), Worobokri (Benue) and Makurdi (Benue), obtained from Nigeria Hydrological Services Agency (NIHSA) were analyzed. The coefficient of variability (CV) of the peak flow and the long term mean annual peak flow from the stations was calculated and the percentage deviation of 2012 peak flow from the long term historical mean at the stations was established. Image from NigeriaSat X with 32 m spatial resolution in four multispectral channels (Red, Green, Blue and Near Infrared) was used to map the land use and land cover along 2 km buffer of the Niger–Benue Rivers floodplain. The mapping covers from Jederbode through Jebba to Lokoja on the Niger and from Worobokri through Makurdi to Lokoja on the Benue River (Fig. 2). A pragmatic land use classification scheme (Adeniyi and Omojola, 1999; Odunuga, 2008) that emphasized the hydrological/flood significance of the land cover was developed. In all eight classes of Land cover were identified. The mapping was carried out using on-screen digitizing while the topographic maps, the Nigeria vegetation maps and other ancillary maps/data provided the basic guide for interpretations. The knowledge of the researcher as well as random ground thruthing contributed to the completion of the mapping exercise.

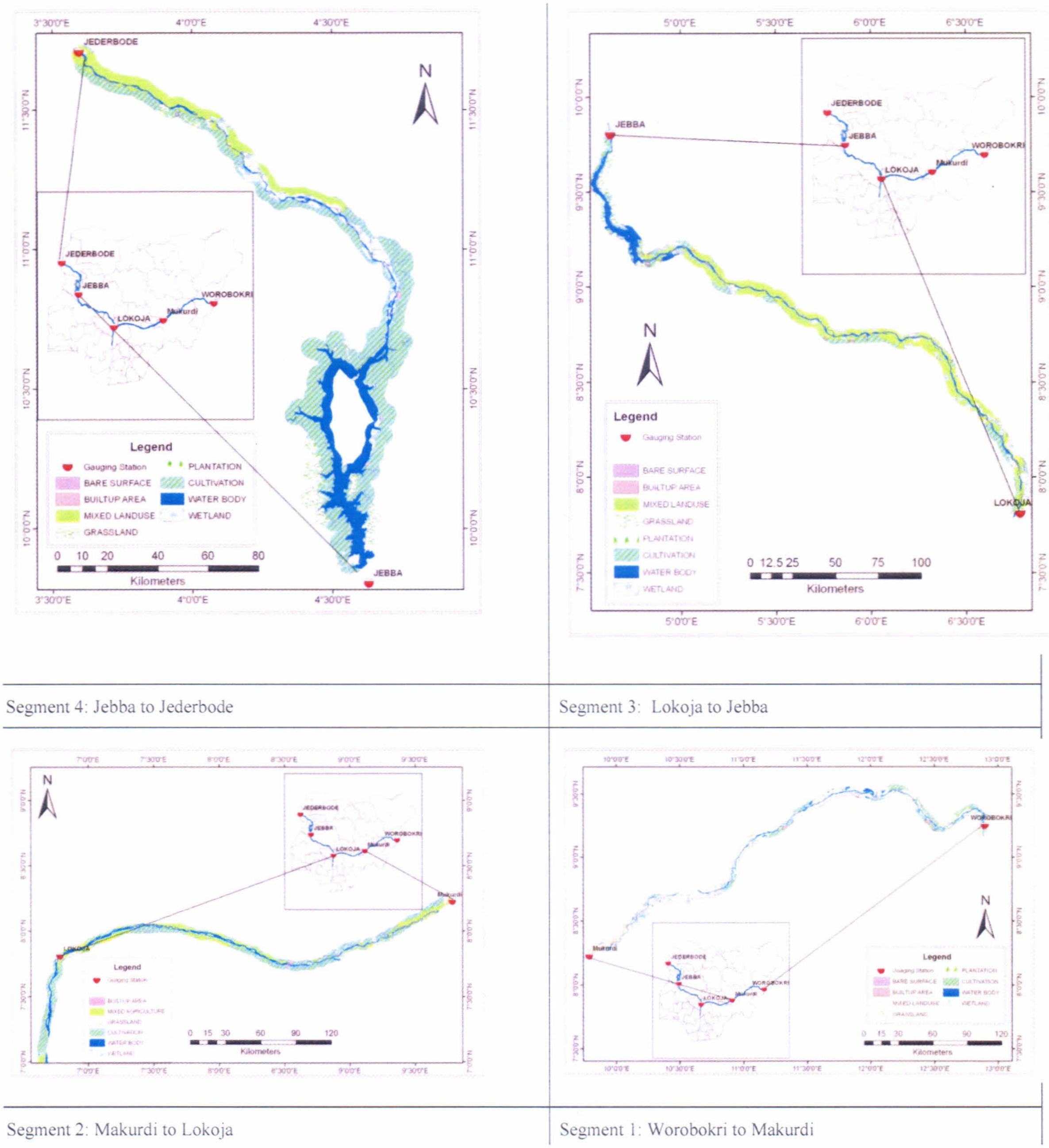
A Flood Plain Vulnerability Index (FPVI) based on two dynamics characteristics (Peak flow (mean and CV), and Land use) was developed for the Niger–Benue Rivers. The study area stretch was divided into four (4) segments (Fig. 2); Worobokri–Makurdi (segment 1), Makurdi–Lokoja (segment 2), Lokoja–Jebba (segment 3) and Jebba–Jederbode (segment 4). A vulnerability scoring for ranges of long term mean annual peak flow was developed (Table 1) to assess the weighted impacts of flow in the channel on the annual flooding of the floodplain. The scores for segments 1and 4 were based on long term mean annual peak flow from Makurdi and Jebba respectively while that of segment 3 and 4 were based on long term mean annual peak flow from Lokoja. Similarly, each of the land uses was assigned a flood vulnerability score that range between 1 and 4 (Table 1) where 4 is the most flood susceptible land use based on past experiences and local knowledge. The permanently water body was not included because it constitutes the perennial water body. The floodplain vulnerability index range was also developed for the vulnerability classes (Low, Medium, High and Very High) and the FPVI class for a particular location is the FPVI range obtained from adding the score that the location obtained from land use, long term mean annual peak flow and coefficient of variability of the peak flow as shown in Eq. (1).

$$\mathrm{FPVI} = X + Y + C \ldots \tag{1}$$

Where $X$ is score of location on land use, $Y$ is the score obtained from long term mean peak flow and $C$ is the score obtained on coefficient of variability (CV) of the peak flow.

## 4 Peak flow analysis

The CV of the peak flow, the long term mean annual peak flow, the extreme peak flow of 2012 and the percentage deviation of 2012 annual flow from the long term mean are shown in Table 2. In 2012, the peak flow at Jederbode (9 September 2012) on the Niger was 3362 $m^3\,s^{-1}$. This is about 50 % above the long term average of 2300 $m^3\,s^{-1}$. Also, the daily flow in 2011 exceeded 2000 $m^3\,s^{-1}$ in 43 days while in 2012 it was exceeded in 80 days. The magnitude and duration of high flow in 2012 was about twice the corresponding value for 2011 (AFO, 2013). At Jebba (Niger), the 2012 peak flow of 1567.6 $m^3\,s^{-1}$ (14 September 2012) is also far higher than the long term mean annual peak flow of 1159 $m^3\,s^{-1}$, though, the flow at Jebba is regulated by Kainji dam. Lokoja (confluence of Niger and Benue) had 2012 peak flow of 31 692 $m^3\,s^{-1}$ (29 September 2012) which is also about 50 % above the historical average of 16 500 $m^3\,s^{-1}$ and the daily flow exceeded the 2011 peak value between September and October. However, the flow in River Niger at Lokoja between January and May 2012 was lower than the flow in 2011 (AFO, 2013). The rate of flow in 2012 at Lokoja increased considerably in June 2012 due to the flood flow in River Benue and River Niger. The Benue at Wuroboki had peak flow of 3362 $m^3\,s^{-1}$ (29 August 2012) which was also much higher than the historical average (694 $m^3\,s^{-1}$). The Benue River at Makurdi had peak flow of 16 387 $m^3\,s^{-1}$ (29 September 2012) which was also unusually higher than




Segment 4: Jebba to Jederbode

Segment 3: Lokoja to Jebba

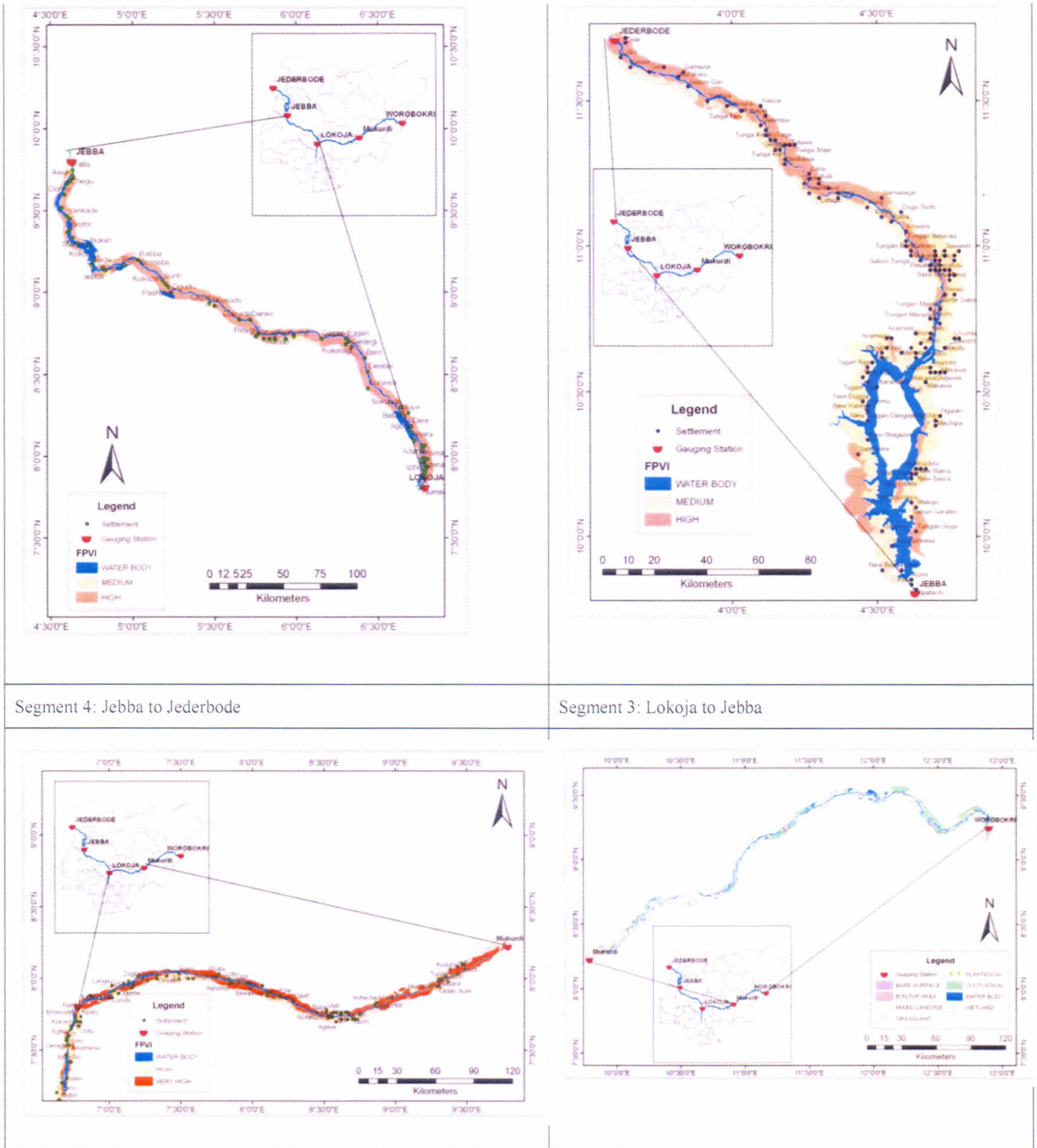
Segment 2: Makurdi to Lokoja

Segment 1: Worobokri to Makurdi

**Figure 2.** Land use distribution along the Niger–Benue floodplain.

**Table 1.** FPVI Scores for Land use, Peak Flow and FPVI index Range for vulnerability classes.

| Land use classes | | | | Long Term Mean Peak Flow | | CV (%) | | FPVI | |
|---|---|---|---|---|---|---|---|---|---|
| Land use | Score | Land use | Score | Range | Score | Range | Score | Vulnerability Class | Range |
| Bare Surfaces | 1 | Plantation | 1 | < 2 000 | 1 | < 25 % | 1 | Low | 1–3 |
| Built-up Area | 4 | Cultivation | 2 | 2001–5000 | 2 | 25–50 % | 2 | Medium | 4–6 |
| Mixed land use | 3 | Water Body | – | 5001–10 000 | 3 | 51–75 % | 3 | High | 7–9 |
| Grass Land | 2 | Wetland | 4 | > 10 000 | 4 | 76–100 % | 4 | Very High | 10–12 |




Segment 4: Jebba to Jederbode

Segment 3: Lokoja to Jebba

Segment 2: Makurdi to Lokoja

Segment 1: Worobokri to Makurdi

**Figure 3.** FPVI for Niger and Benue.

**Table 2.** Peak flow analysis.

| Gauging Station | River | CV (%) | Long Term Mean Peak Flow $m^3 s^{-1}$ (1968–2012) | Annual Peak Flow ($m^3 s^{-1}$) 2012 | Date Of Occurrence Of 2012 Peak Flow | Percentage Deviation Of 2012 Peak Flow From Long Term Mean Peak Flow |
|---|---|---|---|---|---|---|
| Jederbode | Niger | 15 | 2300 | 3362 | 9 September 2012 | 46.21 |
| Jebba | Niger | 18 | 1159 | 1567 | 14 September 2012 | 35.25 |
| Lokoja | Niger | 35 | 16 500 | 31 692 | 29 September 2012 | 92.07 |
| Worobokri | Benue | 16 | 694 | 3362 | 29 August 2012 | 384.44 |
| Makurdi | Benue | 17 | 3042 | 16 387 | 29 September 2012 | 438.63 |

**Table 3.** Land use along the Niger–Benue Floodplain.

| S/N | Land Use/ Land Cover | Area ($km^2$) | Percentage of LULC |
|---|---|---|---|
| 1 | Bare Surface | 48.04 | 0.31 |
| 2 | Built-up Area | 103.91 | 0.68 |
| 3 | Mixed Land Use | 5654.46 | 36.85 |
| 4 | Grassland | 946.92 | 6.17 |
| 5 | Plantation | 6.03 | 0.04 |
| 6 | Cultivation | 4821.07 | 31.42 |
| 7 | Water Body | 2276.07 | 14.83 |
| 8 | Wetland | 1488.88 | 9.70 |
| | Total | 15 345.36 | 100 |

the historical average of 3042 $m^3 s^{-1}$. Apart from Jebba which is highly regulated by Kainji dam, the percentage deviation from the long term mean annual peak flow is about 46 % at Jederbode and 92 % at Lokoja while that of the Benue is over 300 % at Worobokri and over 400 % at Makurdi. The flow in the Benue which increased considerably from June 2012 was due to the flood flow from Lagdo dam in Cameroun. The release of water from the dam, however, was due to unusual rainfall in the Central Africa Region. These extreme deviations are a pointer to the changing flood risk of the Niger–Benue as manifested in the 2012 National Flood Disaster.

## 5 Land use analysis

Table 3 shows land use distribution along the Niger–Benue floodplain. The mixed land use that supports diverse ecosystem services has the largest cover of 5654.46 $km^2$ constituting 36.85 % of the total land area of the floodplain. The bare surfaces which in most cases are morphological rock outcrop by the bank of the rivers have the least area coverage of 48.08 $km^2$ (0.31 %). In all, the land uses of the Niger–Benue floodplain shows that the floodplain supports diverse anthropogenic activities including; human habitation, cultivation, animal rearing, fishing, hunting and transportation. This shows the complex ways by which land use and land cover are linked to hydroclimatic fluxes (Odunuga and Oyebande, 2007). Figure 2 shows the land use distribution along the Niger–Benue floodplain.

## 6 Flood Plain Vulnerability Index (FPVI)

Table 4 and Fig. 3 show the floodplain vulnerability levels of the Niger–Benue floodplain. The Flood vulnerability index of Benue River include; medium, high and very high vulnerability levels. About 83.52 % (1370.08 $km^2$) of the Benue floodplain between Worobokri and Makurdi falls within high vulnerable levels while remaining 16.48 % (270.36 $km^2$) falls within medium level. High vulnerability level constituted 82.32 % of the floodplain between Makurdi and Lokoja on

**Table 4.** Vulnerability Index of the Lower Niger–Benue Floodplain.

| Location | River | Floodplain Vulnerability Levels ($km^2$) | | | |
|---|---|---|---|---|---|
| | | Low | Medium | High | Very High |
| Worobokri–Makurdi | Benue | | 270.36 | 1370.08 | |
| Makurdi–Lokoja | Benue | | | 5417.06 | 1163.07 |
| Lokoja–Jebba | Niger | | 698.07 | 1916.62 | |
| Jebba–Jederbode | Niger | | 2779.52 | 1554.17 | |

the Benue River while the remaining (17.68 %) has very high vulnerability flood level. The high flood susceptibility of the floodplain between Makurdi and Lokoja as revealed by its high and very high vulnerability levels might have contributed to severe impacts that the 2012 National Flood Disaster had on the inhabitants of this area. However, if reservoir operations in the upstream Lagdo dam are rational, the Benue valley agricultural activities may be boosted as opposed to the 2012 destruction of farmlands by flood.

The Niger River floodplain on the other hand exhibits medium and high vulnerability levels from Jederbode to Lokoja (Table 4). It can therefore be explained that, any year that hydrological processes especially the peak flow event is above the long term historical average on the Niger, settlements between Jederbode and Lokoja in Nigeria will experience flood and the reservoir (Kainji dam) on the Niger within this segment will receive enough to operate at full capacity. However, if best practices in dam operation and reservoir optimization are not used, the downstream population will be highly impacted. The severity of impact may be much higher if corresponding high flow comes from the Benue River as it occurred in year 2012. Also, the floodplain vulnerability of Niger around the confluence and downstream of Lokoja to the acute delta will probably be very high class. This agreed with the results of (Nkeki et al., 2013) which identified high population at risk.

## 7 Governance/adaptation strategy

Based on the administrative/governance structure and functionality in Nigeria (Federal, State and Local Governments) as well as the results of the Niger–Benue floodplain land use activities and flood vulnerability analysis, adaptation strategy for sustainable agricultural practices along the floodplain is proposed. The strategy is hierarchical and the implementation hierarchy includes: community concern, local authority concern, state concern and national concern.

The national concerns includes; multilateral cooperation on the international rivers (Niger and Benue), the development and maintenance of critical infrastructures such as reservoirs, river monitoring, development of infrastructures for early warning systems and provision of enabling environment to enhance flood plain agriculture and subsidize farmers affected by flood related hazards. The state concerns includes: the development and implementation of dynamic flood plain land use strategies based on floodplain vulnerability index scenario analysis, identification of the Niger–Benue Rivers flood plain users and organizing them into groups under state institution, provision of technical support including extension services, legislature and funding of new incentive-based programmes to promote the widespread and mainstream new adaptation policy. The local authority concerns includes: public awareness on a range of issues including annual flood outlook, land use policy, climate change, efficient water use, other government policies, adoption of new innovative technology including capacity building of flood plain users etc. The community concerns will include: complying with state and local authority directives and adoption of new technology and innovation in the utilization of Niger–Benue River floodplain.

## 8 Conclusions

Based on the analyses of historical and recent flood (peak flow) of the Niger and Benue Rivers at strategic locations, the land use analysis and Floodplain Vulnerability Index analysis, the paper develops a hierarchical adaptation strategy for sustainable use of the Niger–Benue River floodplain. It is recommended that the strategy proposed be adopted by all concerned authorities so as to ensure sustainable development of rich agricultural land of the Niger Benue floodplain.

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